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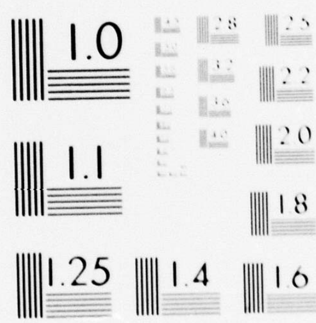

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Dennis R. Weller
Human Factors Laboratory
Naval Training Equipment Center
Orlando, FL 32813

April 1979

Interim Report for Period October 1978 - February 1979

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This report discusses the concept of predictor displays and their potential application to the training of carrier landings. Topics covered are the history of predictor displays, display design considerations, new display formats, factors to be addressed in future display development, training strategies, and expected benefits. It is concluded that the use of predictor displays in carrier landing training is a promising research area.

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SUMMARY

This report discusses the concept of predictor displays and the potential application of such displays to the training of carrier landings. The history of predictor displays is reviewed, with special emphasis on displays used for aircraft landings. Display design considerations are discussed, and new display formats for carrier landing are suggested. Factors which should be addressed in the future development of predictor displays are presented, along with possible strategies to be used in applying these displays as training aids. Finally, the benefits which should result from the successful development of predictor displays as a carrier landing training aid are discussed.

It is concluded that the use of predictor displays in this application is a worthwhile and promising topic for further research.

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SECTION I

BACKGROUND

A predictor display is one which displays the future state of a controlled vehicle or process. The future state is predicted using knowledge of the dynamics of the system, its current state, and the current control inputs. Using the example of an aircraft, a predictor display would show the aircraft's position at some future time, and possibly its future attitude and the path by which it would reach the future position. The predictor display would be generated by a computer which would take information on the aircraft's current state and control inputs and use this as input to a program which would model the dynamics of the particular aircraft. This dynamic model would calculate the future state of the aircraft, which would then be displayed.

The history of the predictor display can be traced back to the work of Ziebolz and Paynter (1954). They proposed an automatic system controller which would use a computer model of the system, operating at faster than real-time rate. The model would be able to determine future system conditions, and discrepancies between predicted and desired values could be corrected automatically before their occurrence. For example, imagine a steam power plant in which a fast-time model is used to predict future boiler pressure using current values of control settings, temperature, pressure, flow rates, etc. If the fast-time model predicted an over-pressure condition at some future time, the current control settings could be automatically altered to prevent the over-pressure from occurring.

Kelly (1958) proposed the use of a fast-time model in manual control tasks; in effect replacing the automatic controller with a human operator. Since that time, Kelly and other researchers have investigated the use of predictor displays in a wide variety of applications, including:

a. Aircraft control (e.g., Kreifeldt and Wempe, 1973; Roscoe, 1976)

b. Aircraft landing

c. Remotely piloted vehicle landing (e.g., Smith and Queen, 1976)

d. VTOL landing (e.g., Kemp, 1969)

e. Aircraft terrain avoidance (e.g., Williams, 1969)

f. Spacecraft rendezvous and control (e.g., McCoy and Frost, 1965)

g. Submarine control (e.g., McLane and Wolf, 1966)

h. Ship control

i. Lunar rover vehicle control (e.g., Arnold and Braisted, 1963)

These studies have consistently demonstrated improved performance with the use of predictor displays. In addition, some of these studies have found

positive transfer from predictor to non-predictor displays, indicating the potential training value of predictor displays. Despite these positive results, there is little evidence that predictor displays have been implemented, either as operational devices or as training aids.

The lack of implementation of predictor displays may be the result of a lack of in-depth research and development on specific applications. Most of the past research in the area has consisted of feasibility demonstrations, with little work directed toward making predictor displays operational. It appears that more comprehensive research on specific applications is called for, with attention being focused on concrete payoffs to be realized from the use of predictor displays.

The remainder of this report considers one such specific application; the use of predictor displays as an aid in the training of aircraft carrier landings. However, much of what is said would apply to a variety of aircraft operations, and also to the operation of other vehicles.

More detailed histories of the development of predictor displays can be found in Smith and Kennedy, 1976; and Warner, 1969.

SECTION II

PREDICTOR DISPLAYS PROPOSED FOR AIRCRAFT LANDING

Before reviewing previous research related to aircraft landing, it is necessary to define some predictor display terminology. The Prediction Span is the span of time covered by the predictor display (i.e., how far into the future the predictor predicts). The Stick Assumption is an assumption concerning the movements of the control stick which will be made during the prediction span (e.g., the current stick position will be held for one second, then the stick will be returned to the neutral position). A stick assumption is required in the aircraft landing situation because it is unrealistic to assume that any stick deflection will be held for an entire prediction span.

The studies reviewed in this section are grouped according to the type of display used.

SIDE-VIEW DISPLAYS

One type of predictor display used in aircraft landing research is the side-view display shown in Figure 1. This display gives information only on the vertical position of the aircraft, although a second, horizontal display of the same type could easily be developed.

A study by Smith, Pence, Queen, and Wulfeck (1974) used a side-view display in a simulated landing of a T-37 aircraft. Flight-naive subjects were used. Three prediction spans were tested (5, 10 and 20 seconds), along with three adaptive modes (the predictor trace appeared when the aircraft was predicted to go out of tolerance in 0, 5 or 10 seconds). Subjects using the predictor display performed more accurate approaches, in terms of airspeed and altitude control, than control subjects who had no predictor trace. The longest prediction spans and adaptive modes gave the best results. Also, positive transfer was demonstrated, in that subjects trained with the predictor showed better performance on subsequent non-predictor landings than control subjects.

Another study using a side-view predictor display in a simulation of a T-37 landing was conducted by Kennedy, Smith, Queen, Burger, and Wulfeck (1975). This study investigated three prediction spans (10, 20, and 30 seconds) and three stick assumptions (return to neutral in 0, 1, or 3 seconds). The subjects had some prior simulator experience. Results showed that all predictor conditions were superior (in altitude control) to a non-predictor control. There were no significant differences between prediction spans or stick assumptions.

A study by Smith and Queen (1976) used a side-view predictor display in a simulation of the landing of a remotely piloted vehicle. The predictor display resulted in superior performance in this task also.

A particular advantage of the side-view predictor display is that it gives a good view of the future path of the aircraft as well as its future position. It was found that subjects made extensive use of this flightpath information. As they became more experienced, they paid less attention to

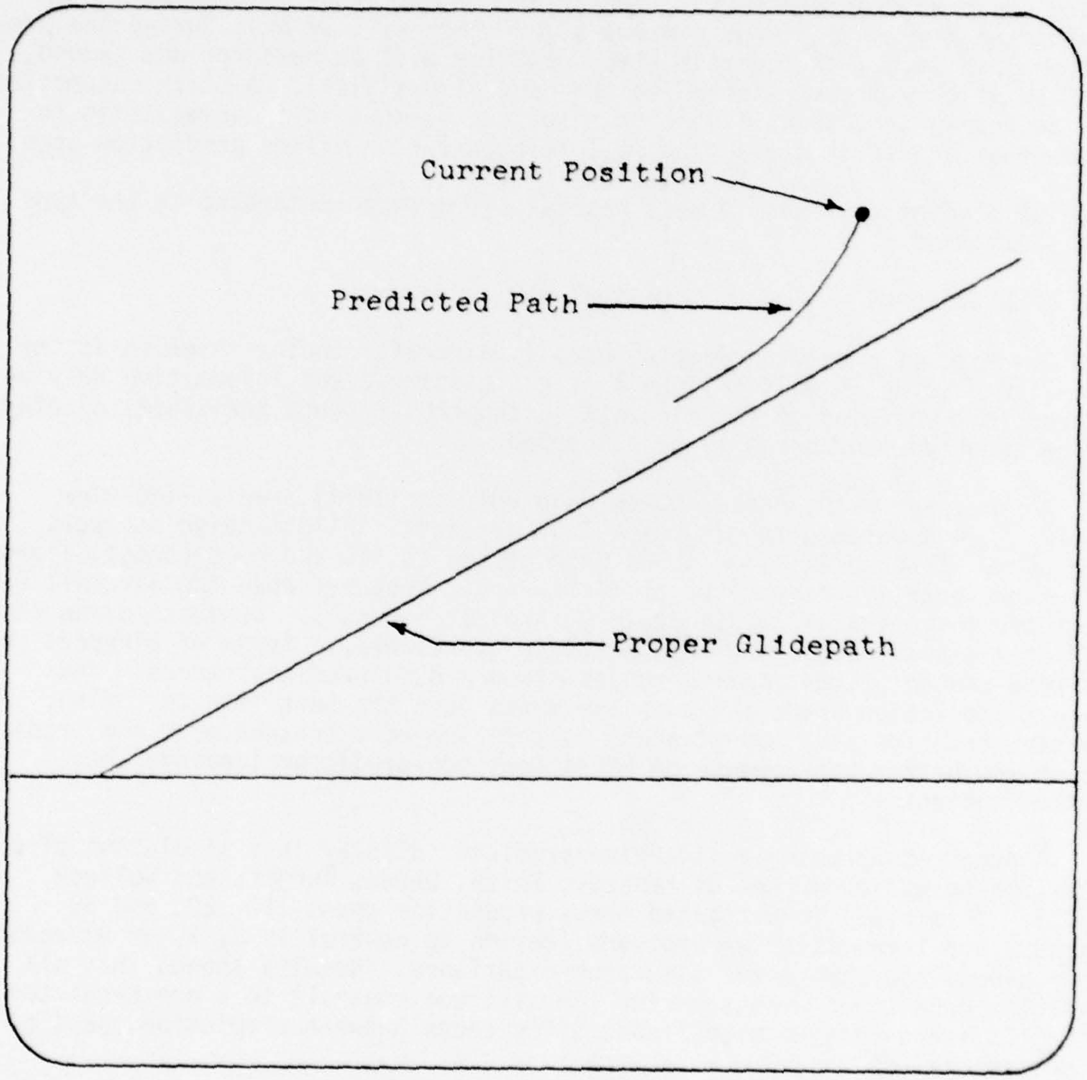

Figure 1. Side-View Display

the end point of the predictor trace, and instead adopted the tactic of bringing the earlier, more curved, portion of the trace tangent to the desired glidepath. This technique effectively brought them on-glidepath in the shortest possible time.

TUNNEL/FLIGHTPATH DISPLAYS

A tunnel/flightpath display is shown in Figure 2. In this display, the viewer looks along the flightpath of the aircraft, rather than perpendicular to it, as in the side-view. The glidepath element consists of a series of rectangles, all the same size, which are centered on the glidepath and spaced at even intervals along it. This gives the impression of a tunnel when viewed from a position near the glidepath. The predictor portion of the display is a solid pathway, with the farthest (shortest) end representing the future position and attitude of the aircraft, and the nearest (longest) end representing current position and attitude. This pathway gives some impression of curvature of the future flightpath, although it is inferior to the side-view in this respect. It is difficult to create an effective impression of a curved flightpath in a display which looks along the flightpath.

This display was used in a study of the simulation of a carrier landing with an F-4 aircraft, reported by Kennedy, Wulfeck, Prosin, and Burger (1974). The subjects were night carrier qualified F-4 pilots. A 30 second prediction span and a 1 second stick assumption were used. Performance using the predictor display was compared to performance on a non-predictor simulation of a night carrier landing. It should be noted that the predictor display did not include any representation of a carrier. Performance with the predictor display was clearly superior on all measures. Performance with the tunnel portion of the display alone was also measured and found superior to the non-predictor simulation, but inferior to the full predictor display.

A follow-on to this study was reported by Kennedy, et al. (1975). The displays were the same as in the previous study, but the subjects were pilots who were not qualified in the F-4 aircraft. Once again, performance measures showed the predictor display best, the glideslope tunnel alone next, and the non-predictor simulation worst. Two additional results of this study are notable. First, the subjects in this study (not F-4 qualified) performed as well on the predictor display as the subjects of the previous study (F-4 qualified), although they did not perform as well with the other two displays. This indicates that the predictor display allowed very rapid acquisition of the necessary skills. Also, subjects in the second study who received the non-predictor simulation last (different subjects received displays in different orders) performed 100 percent better on this display than subjects who received it first or second. This indicates considerable positive transfer from the predictor (or tunnel) display to the non-predictor simulation. Learning effects of this magnitude were not found with other display orders.

PICTORIAL PREDICTOR DISPLAY

A pictorial predictor display, as described by Jensen (1978) and Roscoe (1976) is shown in Figure 3. It includes a simulated out-the-window view of the horizon and runway. The glideslope reference in this display is provided by the vertical "posts", the tops of which define the proper glideslope.

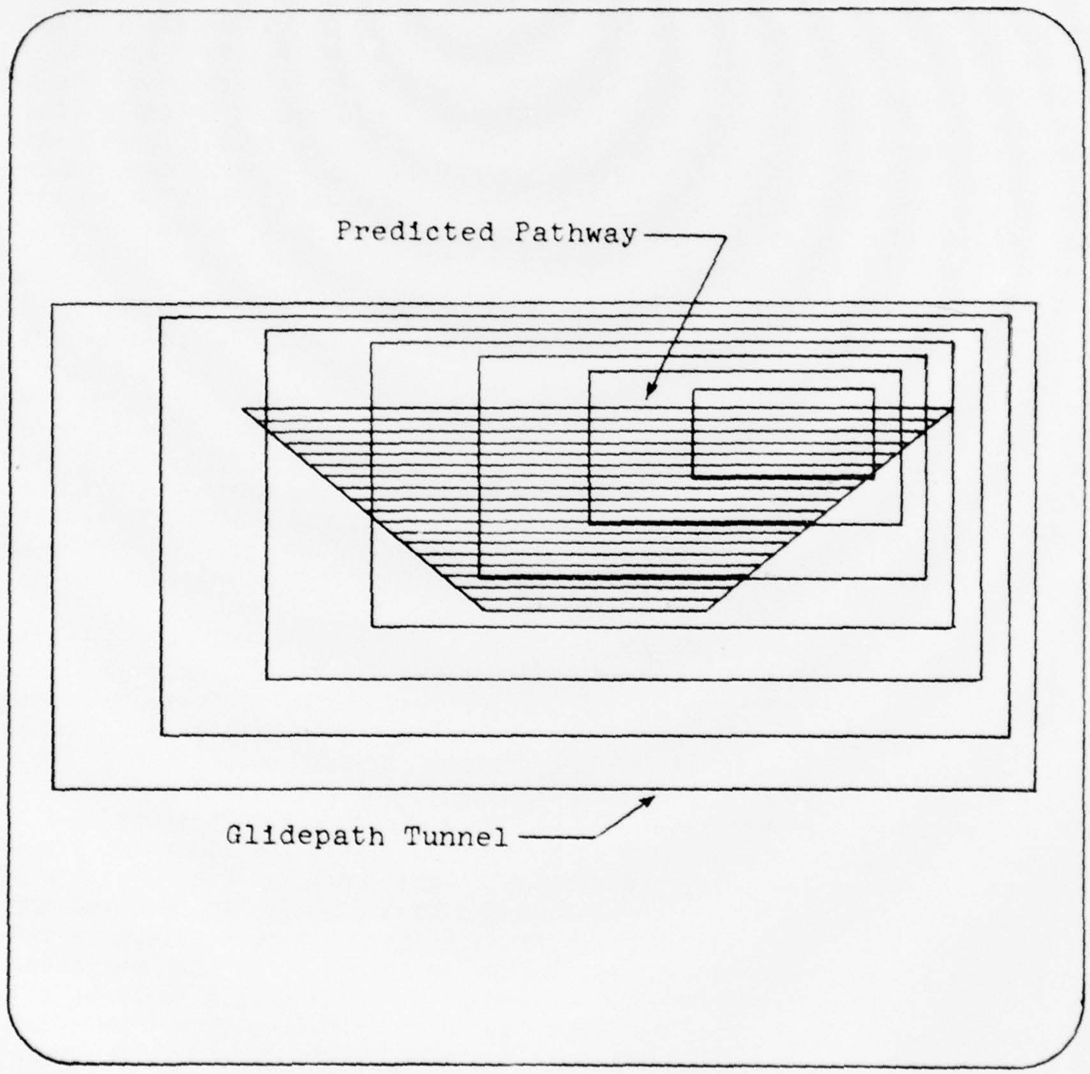

Figure 2. Tunnel/Flightpath Display

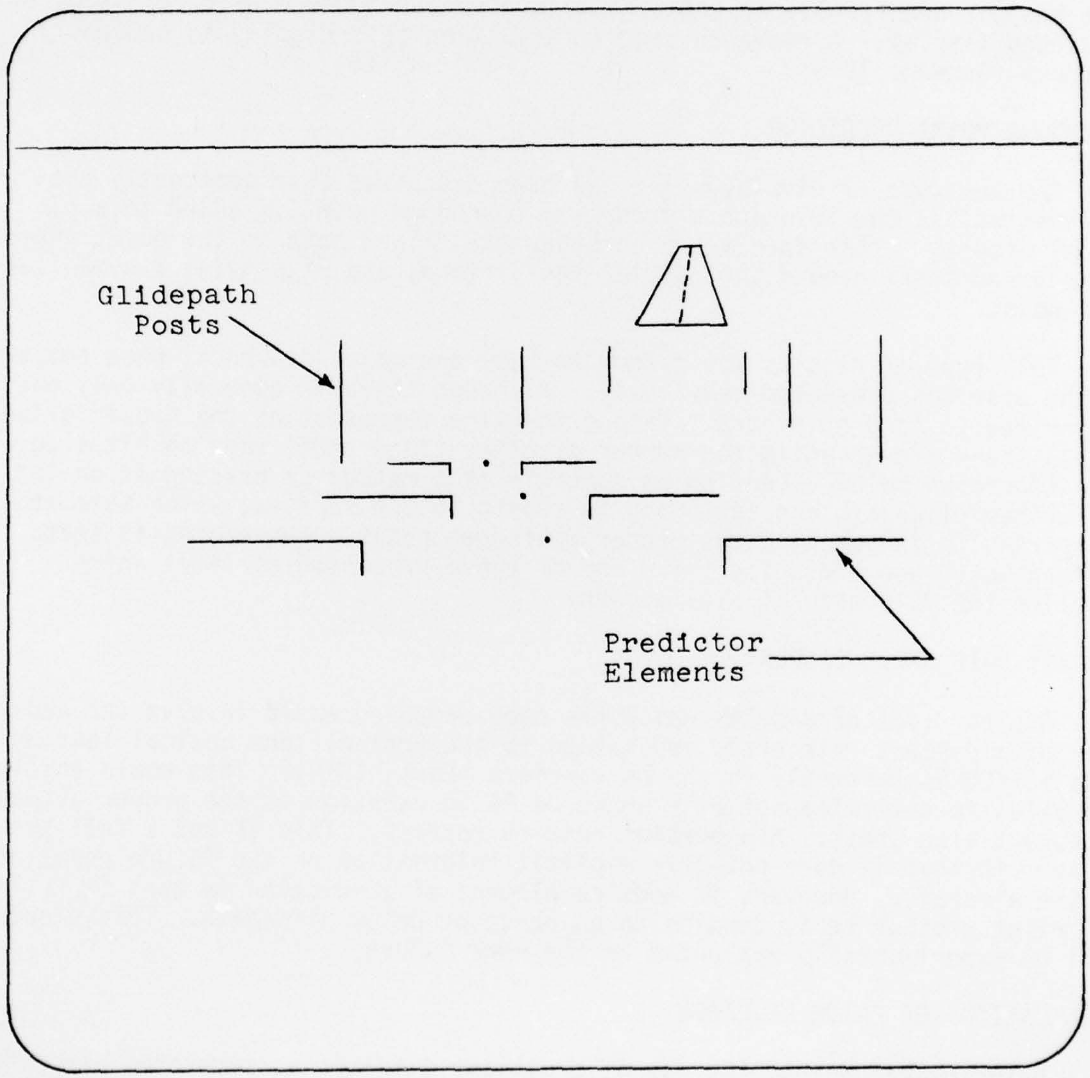

Figure 3. Pictorial Display

Three predictor elements are provided, representing the aircraft position and attitude at three time spans (the smallest element is the farthest into the future). This portion of the display is similar to the tunnel/flightpath display, except that there are only three discrete elements, rather than a continuous path. It is probable that this display provides less curvature information than the tunnel/flightpath display. The perception of depth in this display is aided by varying the thickness and intensity of the predictor elements and "posts".

Data has not been published concerning landing performance with this type of predictor display. A research program involving this display is currently underway (Jensen, 1978).

TOUCHDOWN POINT PREDICTOR

Another type of display which has been discussed (but apparently not implemented) is one in which a predicted touchdown point is added to a pictorial display. This involves predicting the flight path to the point where it intersects the ground (or carrier deck) plane, and displaying a symbol at this point.

This type of display would seem to have one major drawback, when compared to the displays presented previously. Although there is generally only one proper way to land an aircraft (along the line representing the proper glidepath), there are an unlimited number of other (incorrect) ways to hit a certain touchdown point. Landing an aircraft is a matter of placing it on the prescribed glidepath and following this path to the surface, which automatically results in reaching the proper touchdown point. Therefore, it seems preferable to use a display (like any of those presented earlier) which involves the following of a glidepath.

DESCENT RATE ERROR DISPLAY

Another type of display which has been proposed would involve the addition of a descent rate error indication to the fresnel lens optical landing system (FLOLS) currently in use on carriers (Kaul, 1978). This would enable the pilot to determine not only where he is in relation to the proper glidepath, but also whether his descent rate is correct. This is not a full predictor, in that it does not give explicit information on the future position of the aircraft. However, it adds an element of prediction in that it tells the pilot whether he is tending to go above or below glidepath. This display will be experimentally evaluated in the near future.

IMPLICATIONS OF PRIOR RESEARCH

Prior research into the use of predictor displays in simulated aircraft landing has consistently shown that these displays improve landing performance. Furthermore, there is evidence that positive transfer occurs between predictor and non-predictor displays. Therefore, the further investigation of predictor displays as an aid in the training of carrier landings is clearly indicated.

SECTION III

DISPLAY DESIGN CONSIDERATIONS

The past work on predictor displays for aircraft landing has not included the development of a display specifically designed as a training aid. This application involves special considerations, primarily related to the transfer of training. It is assumed in this discussion that a predictor display would initially be implemented in a simulator, although placing a predictor display in an aircraft is certainly feasible.

DISPLAY TYPE

All simulators for carrier landing use pictorial displays. This is imperative, since external visual cues are used almost exclusively during the actual carrier approach (Kennedy et al., 1974, p. 17). Since a pictorial simulation would be the transfer task after training with a predictor display, the predictor display should be one which can coexist with a view of the aircraft carrier. That is, the prediction symbology should ideally be placed in the same visual "world" with the carrier. This would allow the student to become accustomed to the appearance and dynamics of the actual visual scene while using the prediction elements.

This is not to suggest that training on a predictor display which does not coexist with the visual scene, such as a side-view display, would not transfer to a pictorial display. However, maximum transfer can be expected to occur when the predictor and transfer displays are as similar as possible.

Another approach would be to add a side-view (or other non-pictorial) predictor display as a separate instrument in the cockpit of a simulator. This would enable the student to alternately view the pictorial scene and the predictor. However, in the critical stages of final approach to a carrier, it is inadvisable to force the pilot to take his attention away from the external scene. It would be better to place all necessary information in the external visual field. Placing a side-view predictor display in the cockpit would cause another problem, in that the pilot would be alternating his attention between two views of the world which are rotated 90^{o} from one another. Furthermore, one of these "worlds" would be moving, while the other world would be fixed. These problems could cause control/display confusion.

NON-INTERFERENCE OF PREDICTOR DISPLAY

If a predictor display is to coexist with a pictorial view of a carrier, the problem of interference arises. For example, if the tunnel/flightpath display of Figure 2 were placed in the same visual scene as a carrier, it would clearly interfere with the view of the carrier. Ideally, the predictor elements should not interfere at all with the carrier picture. The predictor display of Figure 3 comes close to this criterion, although there is some interference. The next section presents some other approaches to this problem.

SECTION IV

OTHER APPROACHES

Two additional predictor display formats are suggested here which could be applied to the carrier landing situation. Figure 4 shows a tunnel/side-view display. It includes a tunnel formed of a series of squares centered on the glidepath, similar to the display in Figure 2. On the "ceiling" and one "wall" of the tunnel, horizontal and vertical projections of the predicted flightpath are presented, along with projections of the desired glidepath. These can be visualized as "shadows" of the flightpath and glidepath. This retains one of the valuable features of the side-view display; the explicit representation of curvature of the future flightpath and its relation to desired glidepath (although some curvature information is lost through foreshortening). It also uses the abundant glidepath cues of the tunnel/flightpath display. The tunnel elements in such a display could be scaled to represent squares having sides of about 100-200 feet, so that glidepath deviations generally found in carrier approaches (less than 50 feet) would be clearly visible. If a tunnel of this size were continued all the way to the carrier deck, the far end would obviously interfere with the carrier picture. This could be avoided by displaying only a portion of the tunnel at any one time (i.e., the next 1,000 feet).

A possible drawback to this type of predictor display is that it includes no explicit representation of current aircraft position (unless a display with a 180^{o} field of view is used). However, the nearest point of the prediction trace would represent a time only about 3-5 seconds into the future (assuming an average size CRT (cathode-ray tube) display) and the loss of this portion of the trace would not seem to be critical. Also, the tunnel elements and the picture of the carrier and FLOLS (Fresnel Optical Landing System) provide ample cues concerning current position.

Another possible format, the dot/circle display, is shown in Figure 5. This predictor display consists of only three symbols; a cross representing current position, a dot representing future position, and a circle representing glideslope. The circle would be positioned to represent a point on the glideslope at the same distance from the carrier as the dot representing future position. The landing task would be basically reduced to a tracking task with the pilot attempting to move the dot into the circle. The cross would, of course, follow the dot.

This symbology can coexist with a pictorial view of the carrier, and it would only cause minimal interference with the carrier picture. It is similar to elements of the integrated aircraft display described by Roscoe (1976). One element totally lacking in this display is an explicit representation of the curvature of the predicted flightpath. It should be noted, however, that information on flightpath shape can be inferred from the relative motions of the symbols. For example, if the dot (future position) is seen to move away from the cross (current position), this indicates a curvature toward the position of the dot. This information is obviously less precise than that given by an actual plot of future flightpath.

These two displays are only suggestions of formats which may be of value in the carrier landing situation. It should be evident that there is an

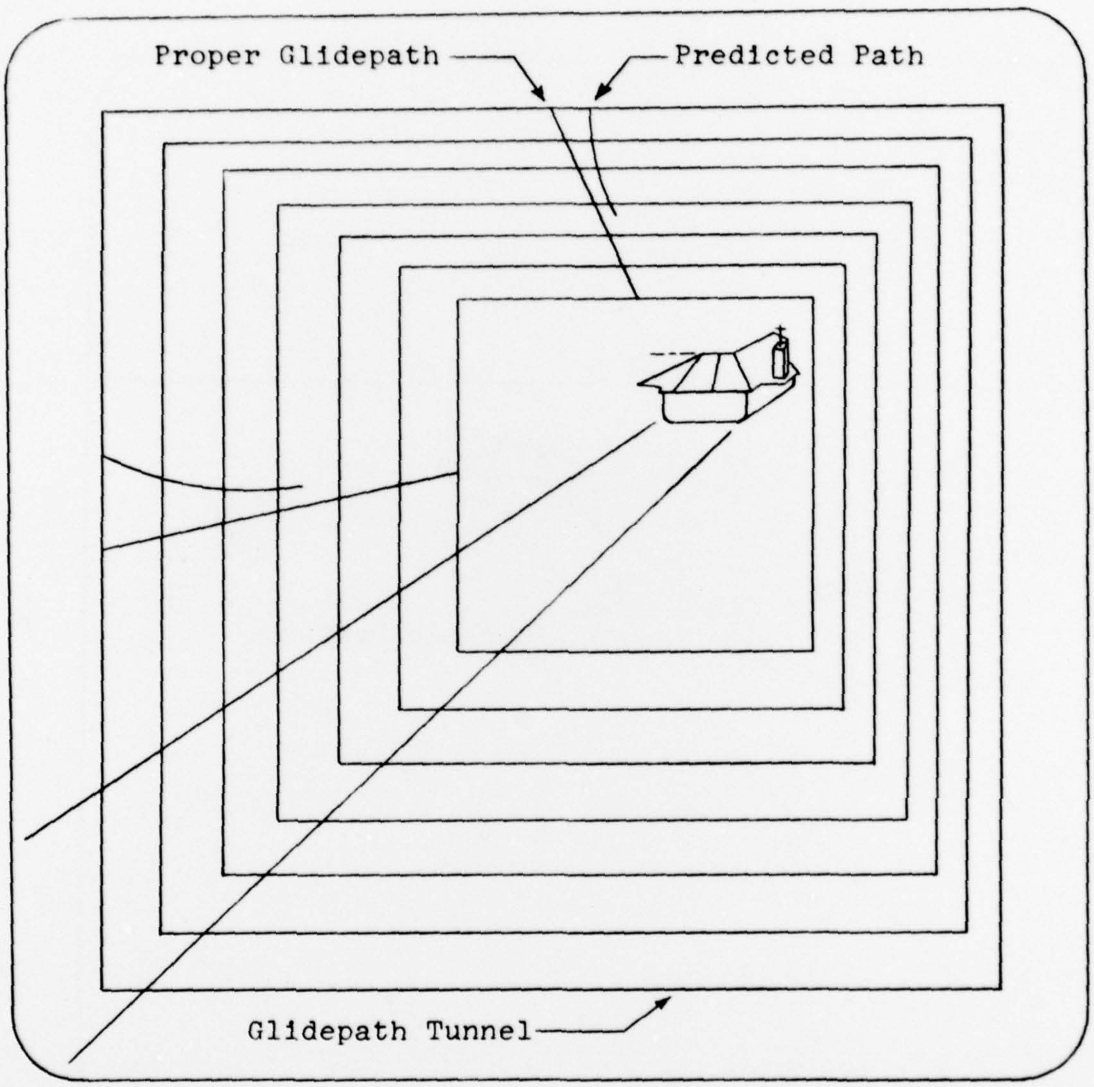

Figure 4. Tunnel/Sideview Display

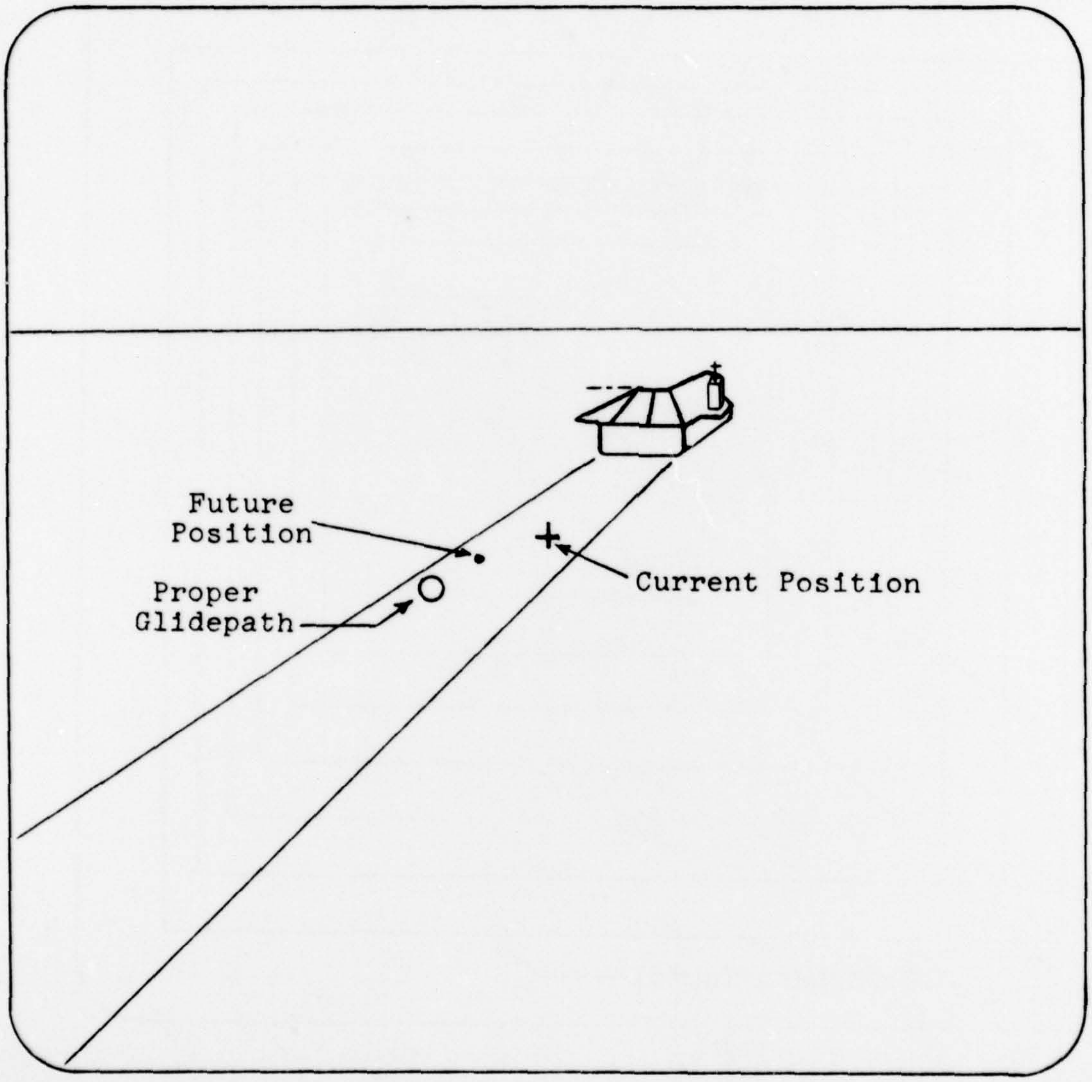

Figure 5. Dot/Circle Display

unlimited number of possible predictor display designs. Furthermore, the possible value of such displays cannot be determined from static drawings. It is necessary to see them operating dynamically in order to evaluate their potential.

SECTION V

DISPLAY DEVELOPMENT

The first task in the development of a predictor display for training carrier landings is the optimization of the effectiveness of the display. The effectiveness of a predictor display would be determined by the degree to which it increased the accuracy of glidepath tracking. Some of the major factors which should be addressed in the development of a predictor display are discussed below.

DISPLAY FORMAT

Display format is one factor which can be expected to have a great influence on predictor display effectiveness. Unfortunatley, this is a difficult factor to quantify. As noted in the previous section, there are unlimited possibilities for predictor display format. An appropriate first step in the process of display development would be to generate a wide variety of possible predictor display formats. These displays could then be divided into groups according to whatever criteria seem applicable, and representative displays from each group could be chosen for further study. Obviously, a considerable degree of subjectivity would be involved in this process.

In the initial evaluation of display formats, the stimulus value of a display could be tested without requiring control responses by the subject. This would involve showing subjects prerecorded approaches using a predictor display. The prerecorded approach would be stopped at various stages, and subjects would be asked questions such as, "where is the aircraft now", "where will the aircraft be in 30 seconds", and "where will the aircraft touch down." This procedure would indicate how clearly the relevant information was being presented by a given display. The advantages of this technique are that it could be accomplished with simple equipment (e.g., a videotape recorder) and with non-pilot subjects.

PREDICTION SPAN

Another potentially important factor which requires further study is prediction span. Previous research is unclear as to the effect of prediction span on simulated landing performance. Smith, et al. (1974) found that longer prediction spans yielded better performance, while Kennedy et al. (1975) found no difference across prediction spans.

STICK ASSUMPTION

Stick assumption has not been extensively studied for its influence on predictor display effectiveness. The study by Kennedy, et al. (1975) found no difference in performance across three stick assumptions. Further study of this variable might use a wider range of values. Another approach would be to vary the stick assumption as a function of aircraft deviation from glidepath. For example, if the aircraft were far from glidepath, the stick deflection might be held for a longer period of time than if the aircraft

were close to glidepath. The shape of the stick input is a factor which could also be varied. Previous studies have assumed, in the fast-time models, that all stick movements are made instantaneously (i.e., step inputs). Other, more realistic shapes for stick inputs might result in more accurate predictions. Data could be collected on actual stick inputs during real or simulated carrier landings to determine appropriate stick assumptions and input shapes to be used.

PREDICTION MODEL

Most of the studies done on predictor displays have used a fast-time model of vehicle dynamics. However, simpler prediction methods have been proposed, including a simple extrapolation of current rates of change and a correlational technique wherein current vehicle variables are used to predict future conditions via least-squares multiple regression equations (Gallaher, Hunt, and Williges, 1976). Such techniques have been found to yield usable predictions. The argument for using simpler models is that they can be calculated with computer equipment which is smaller, lighter, and less complex than that required for a fast-time model. However, since initial work on predictor displays will probably be done on ground-based simulators, these factors are not critical. Furthermore, with the rapid developments in microprocessor technology, the use of a full, fast-time predictor model in an actual aircraft would probably involve little penalty versus the simpler and less accurate techniques. A point to be kept in mind, however, is that the accuracy of any aircraft dynamic model is limited by the availability of good aerodynamic data for the aircraft.

CONTRIBUTION OF GLIDEPATH ELEMENT

Another factor which should be addressed in the development of a predictor display is the effectiveness of the glidepath element. All predictor displays used in the aircraft landing studies have included a glidepath element which is not generally available in the operational situation. A glidepath element alone, without a predictor element, can be expected to improve performance over a display with no glidepath element. The study by Kennedy, et al. (1974) reported that the tunnel glidepath element did improve performance above that of the non-predictor simulation, but not to the level of the full predictor display. A study by Lintern (1978) found improvements in simulated landing performance using a glidepath display similar to that of the pictorial predictor display. Future display development should include the separate evaluation of the glidepath element, so that its contribution to any performance improvements can be determined.

SECTION VI

TRAINING STRATEGIES

Once an effective predictor display (or displays) has been developed, the next task is to develop an effective training strategy for use of the display. The training strategy would probably involve initial training with the predictor elements available 100 percent of the time. The predictor display would be gradually phased out until the student was able to land successfully with no prediction. The student would thus be forced to rely less on the cues available in the predictor display, and more on the cues available in the visual scene, as he progressed through the training. Some of the possible methods for gradually eliminating the predictor display are:

a. Eliminate the predictor display at successively earlier points in the approach.

b. Cycle the predictor display on and off, decreasing the proportion of time during which it is on.

c. Present the predictor display only when the aircraft is outside some tolerance envelope (or when it is predicted to fall outside the envelope).

d. Place the predictor display under pilot control with instructions to decrease its use.

Methods A and B could be done adaptively, such that the predictor display would appear for less time as student performance improved. Method C is adaptive in itself, since the student would automatically see the predictor display less often as his performance improved. Methods C and D could even be combined, allowing the student to select the predictor display while within the tolerance envelope.

The relative effectiveness of various training strategies can be measured by the time required for the student to transition successfully to the non-predictor situation. It should be noted that the display which yields the best initial performance on the landing task will not necessarily be the one which yields the greatest training effectiveness, since another display might result in better transfer, In fact, it might be found that some combination of predictor displays yields the greatest training effectiveness. For example, one display might be best suited for early training, with another being best for advanced training. Thus, care should be taken to avoid eliminating display formats too early in the development process.

SECTION VII

EXPECTED BENEFITS

The development of an effective predictor display for training carrier landing can be expected to result in better and/or faster training than is available using current methods. This could result in such benefits as a reduction in the amount of field carrier landing practice required, and a reduction in the time required to transition between aircraft types. Such a program could also be expected to yield results which would be of value in other areas. The displays presented in this report would all have potential usefulness in the training of any straight-line aircraft (or spacecraft) maneuver. With modification, they might also be applicable to land and sea vehicles. Aside from training, such displays have obvious value as operational aids. For a discussion of several possible predictor display applications, see Warner, 1969.

Given the encouraging results of past work, the lack of implementation of the concept of predictor displays is somewhat surprising. In fact, there is some evidence of a decline in research interest in the area. As mentioned earlier, what may be needed is the development of a predictor display for an actual application, with objective evidence of benefits in cost, time and safety.

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